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Review of Externality Valuation

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Summary

This report covers the work done regarding assessment of externalities in the project "Investigation of Pricing Incentives in a Renewable Energy Strategy in Thailand".

The report gives a review of different valuation issues, which are used in different externality studies and focuses on why the numbers often are different for the same fuel cycles using different methodologies for assessment of the externalities.

The review of externality valuation focuses in this report on the assessment of environmental externalities, and less attention is paid to the non-environmental externalities.

The report points out different parameters, which are important to consider when externalities estimated for the same fuel cycle in different studies are compared. For instance some studies transfer dose-response functions and monetisation values from other studies. It is in this case important to consider for each of the functions if it is possible to use functions from other studies, or if it is necessary to develop a function for a new region.

An important parameter in estimating externalities based on earlier studies is the fact that some studies only include regional and local impacts and do not take the global impacts related to greenhouse gasses into account. Considerable uncertainty is related to the global externalities regarding time horizon for the greenhouse effect, choice of dose-response function and monetisation values. Assumptions on famine and the monetisation of human life may be the totally dominating factor estimating external costs.

7 studies have been chosen for further analysis and comparison in order to show the variation in external costs. The studies have been chosen in order to cover as well old, well-known studies as new, unknown, but interesting studies. Some of the new studies are based on results from earlier studies, while others implement new ideas concerning the methodology.

Content

Preface

This report covers the work done regarding assessment of externalities in the project "Investigation of Pricing Incentives in a Renewable Energy Strategy in Thailand".

The project has been initiated by NEPO with assistance from DANCED in connection with the on-going strategy development in the field of renewable energy promotion.

The overall purpose of the project has been to elaborate pricing mechanisms to promote renewable energy and to assess the level of pricing incentive taking into consideration the benefits obtained by substituting conventional energy by domestic renewable energy sources.

The project has been performed by RAMBOLL as project manager in collaboration with Risø National Laboratory, Asian Institute of Technology, the EU-ASEAN Cogen Program and IIEC.

Risø National Laboratory has performed international reviews on pricing policies and externality valuation. This report covers the review of externality valuation.

Senior scientist Lotte Schleisner has prepared the report in the spring of 1998.

Risø, November 1998

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1. Introduction

Choosing one energy option or another may influence many aspects of society and the environment, which should be accounted for if we want to obtain the highest benefits for the society. These impacts on society or environment, which are not accounted for, are termed externalities. Externalities related to energy production are in general defined as costs imposed on society that are not accounted for by the producers or consumers of energy, in other words damages not reflected in the market price. Normally, thinking of externalities related to energy, the externalities are environmental. An often cited example is the loss of production in fisheries due to the spill of pollutants in rivers caused by energy use. Public health, agriculture and ecosystems, are other examples of parameters affected by the use of energy by others. The effects may be positive (external benefits) or negative (external costs) and their consideration may make some energy options more attractive than others in spite of their higher costs or vice versa.

In this report the review of externality valuation will focus on the assessment of environmental externalities, and less attention will be paid to the non-environmental externalities.

Over the last decade, several attempts have been made to quantify, and express in monetary terms, the externalities of different energy sources. Externalities may be assessed using different methodologies. Some studies use a “top-down” or macro approach, while others are based on a “bottom-up” or micro approach. Some studies are based on a life cycle assessment, including all impacts from extraction of materials for manufacturing to disposal, while some studies only assess impacts related to the fuel cycle. Especially in the case of renewable energy technologies this will cause a difference in the external costs. Differences in methodologies may also be noticed in the quantification and valuation procedure. Some studies rely on previous estimates, which are not site-specific; other studies rely on abatement costs, being the marginal costs of abating emissions. Other studies use the damage function approach, where the impact from each burden related to the technology is identified, and the damage caused by the burden is quantified and monetised.

An important parameter in estimating externalities based on earlier studies is the fact that some studies only include regional and local impacts and do not take the global impacts related to greenhouse gasses into account. Considerable uncertainty is related to the global externalities regarding time horizon for the greenhouse effect, choice of dose-response function and monetisation values. Assumptions on famine and the monetisation of human life may be the totally dominating factor estimating external costs.

In the following paragraph some of the most important reasons for differences in the numbers are mentioned.

2. Major valuation issues

2.1 Top-down versus bottom-up approach

The “top-down” approach was undertaken by Hohmeyer (1988), and followed by Ottinger et al (1991). It calculates externalities in an aggregated way, typically at a regional or national level. The steps followed by this methodology are the following: first, estimates of total damages from a certain impact are identified from other studies. Then, the fraction of the total impact attributable to a fossil fuel is calculated, to estimate the contribution of this fossil fuel to the total damage. This methodology is useful, because of its relative simplicity, to get a broad view of the damages caused by fuel cycles. However, several drawbacks may be identified. First, this method relies heavily on approximations and previous estimates of total damages. It does not take account of the different fuel cycle stages, and effects due to variations in burdens and receptor distribution are neglected. Therefore, no site-specific effects can be assessed, nor can the effects of additional or marginal impacts be estimated.

Site-specific estimates may be provided by a “bottom-up” approach. The study by Pace (1990) estimated emissions, their dispersal, the population and environment exposed, and the impacts and costs produced. All these estimations came from numerical values from previous studies. The same approach was followed by Pearce et al (1992), who addressed more impacts than Pace. In none of the cases were data collected at the primary level, so they cannot be considered site-specific, as they do not take account of site differences.

The latest approach to externality assessment is that proposed by the ExternE project of the European Commission (1995). This is a bottom-up methodology, which tries to eliminate the problems of other methods. The ExternE methodology is based on a damage function approach, being a series of logical steps tracing the impact from the activity that creates it to the damage it produces, independently for each impact and activity considered. This allows for a marginal, site-specific assessment.

Top-down studies identify average costs, whereas site-specific bottom-up analyses identify the costs associated with marginal impacts. At a policy level top-down analyses are useful, because policies mostly address average costs. On the other hand, for environmental costing purposes the bottom-up analyses are useful whenever possible, because it is the environmental cost of a new proposed resource that must be selected based on marginal costs. However, generic estimates of environmental costs based on top-down analyses are often the only estimates available. Therefore, in the absence of site-specific estimates the generic estimates must be used.

2.2 Damage costs versus control costs

Environmental costs may be estimated either by using damage costs or control costs. Damage costs are the costs of damages inflicted on society by pollutants, while control costs are the costs of controlling or mitigating pollution damages.

The damage costs are the most relevant costs to be used in the assessment of external costs, as it is the damages to the society that are sought to be addressed by incorporating environmental external costs when choosing utility resources. The problem in using damage costs is the difficulty in calculating them.

If damage cost studies are insufficient, for instance in the case of global warming, control costs can serve as a proxy. Control costs are easier to estimate, because data on the costs of control is more readily available. Control costs, however, have no or only minor relationship to the cost of the damages imposed on society by the relevant pollutants.

2.3 Methodology

Earlier studies are mostly literature reviews that take estimates of pollutant emissions and impacts from other studies and then multiply these estimates by economic values. Newer studies use mostly some kind of variation of the damage function approach. This methodology estimates externalities by identifying general pathways for each source of the damage from a LCA point of view. Dispersion models are used to estimate the concentration of the emissions and dose-response functions are used to calculate the resulting health effects and ecological impacts. Different valuation functions are used to calculate the economic damages of the impacts. In some cases computer models have been developed including dispersion models, dose-response functions and monetisation values (European Commission, 1995) (Rowe et al., 1995).

In general the emissions, concentrations and impacts used in the literature based studies are greater than the estimates calculated using the damage function approach.

2.4 Atmospheric modeling

The expected concentration of emissions in different areas away from the plant and the distribution of population and environmental receptors in these areas are important parameters in assessing ecological and health impacts from emissions. Therefore modelling the dispersion of emissions is a very important factor in estimating externalities. Many studies, however, stop at estimates of emissions without atmospheric modelling.

Typically two kinds of models exist, one for local scale modelling and one for regional scale modelling. For local scale modelling a model often used is the Gaussian Plume model. The model neglects chemical reactions, but is detailed in the description of turbulent diffusion and vertical mixing. The concentration distribution into the atmosphere is assumed to have a Gaussian shape. The model assumes idealised terrain and meteorological conditions so that the plume travels with the wind in a straight line. Dynamic features, which affect the dispersion, for example vertical wind shear, are ignored, which limits the model to a region within 50 km of the source. The Gaussian plume model is not feasible for regions with complex topography, and better-adapted models should be used if possible.

On a regional scale chemical reactions cannot be neglected. The annual pollution on a regional scale may be assessed by using a model with a simple representation of transport and a sufficiently detailed representation of chemical reactions. An example of this may be the receptor-orientated Lagrangian plume model.

2.5 Dose-response functions

The term ‘dose-response’ is defined as the response to a given exposure of a pollutant in terms of atmospheric concentration.

Dose-response functions appear in a variety of functional forms. They may be linear or non-linear and contain thresholds (e.g. critical loads) or not. Some of the dose-response functions describing effects of various air pollutants on agriculture have proved to be particularly complex, incorporating both positive and negative effects, because of the potential of certain pollutants, e.g. those containing sulphur and nitrogen, to act as fertilisers.

A major issue with the utilisation of dose-response functions is the assumption that they are transferable from one context to another. For example, some of the functions for health effects of air pollutants are derived from studies in the USA. There may be problems in using these functions for Europe, Thailand or other continents, as there is good reason to suspect that there will be some variation, resulting from the affected population, the exact composition of the pollutants the study group was exposed to, etc.

2.6 Identification of damages

The effects of many impacts are highly dependent on the location and characteristics of the source, the distribution of populations, topography and climate. Therefore, externalities derived in one region or country may not be transferable to another region. Another important parameter in estimating externalities based on earlier studies is the fact that some studies only include regional and local impacts and do not take the global impacts related to greenhouse gases into account.

Local impacts

Local impacts are impacts close to the fuel cycle activity and are typically the result of a burden like noise or visual intrusion in a distance of a few kilometres from a plant. The analysis of local impacts is more straightforward than that for regional or global impacts. Analyses range from the use of statistical data to more elaborate analysis such as the assessment of noise effects. Typically many local impacts are identified, but in practice they are negligible compared to regional and especially global impacts.

Regional impacts

Regional impacts are experienced over long distances affecting a large number of people. Regional impacts are typical impacts related to acid emissions and particulates. Regional impacts are mostly assessed using dispersion models to obtain the regional dispersion. The complexity of the models and data used in regional assessments varies widely.

It may vary which emissions are included in the different studies, and the regional externalities may therefore be much larger in some studies compared to others.

Global impacts

Global impacts are related to CO_2 and other greenhouse gases and the resultant impact is on climate change. Different kinds of control cost approaches may be used to estimate the costs of global warming. Using mitigation costs you predict the environmental impacts of global warming and calculates the cost of enduring or repairing the harm. Another way of using control cost approach is to calculate the costs of reducing the greenhouse gas emissions e.g. by improved energy efficiency. The third approach is to calculate the cost of sequestering the CO_2 emitted to the atmosphere by planting trees or other vegetation that will remove CO_2 from the atmosphere.

There is a number of practical problems in evaluating the possible costs of global warming. The time scale of the effects is very long, which makes it difficult to estimate the extent of human adaptation. In addition, the traditional methods of cost-benefit analysis become very sensitive to the choice of discount rate over such long periods. Considerable uncertainty is related to the global externalities regarding time horizon for the greenhouse effect, choice of dose-response function and monetisation values. Effects of global warming are mostly predicted by use of computer-based analyses. These are able to predict only relatively large-scale weather phenomena such as seasonal temperature changes and broad rainfall patterns.

A number of people has carried out studies of the economic impacts of global warming. None of these have claimed to provide a full valuation of all possible impacts of global warming. Nevertheless, some basis for a methodology has been laid down.

2.7 Economic valuation methods

When damages related to an energy production technology have been identified these need to be monetised. Different methods for economic valuation exist and may be used. The methods mostly applied for economic valuation are accounting methods, revealed preference methods (incl. hedonic pricing) and contingent valuation methods.

Accounting methods

Accounting methods may be used to estimate costs such as medical expenditures, maintenance costs, crop and timber losses with and without the environmental effects. Market prices can often be used directly for pricing the environmental effects. For instance if the effect of a pollutant is reduced yields of a commercial crop, the external cost may be estimated by multiplying the observed market prices of the crop by the reduction in yield caused by the pollutant.

Revealed preference methods (hedonic pricing)

Revealed preference methods are based on observed behaviour, for instance the observed frequency and distance people will travel to enjoy a certain recreation site. The recreation site may be valued by using a demand function that relates the rate of use for visitors to their cost of travelling to the site.

Hedonic price methods use market prices to impute prices to non-market goods and services by comparing the market price of a good, that embodies the non-market service to the price of the same good, that does not embody the non-market service. The difference between the two prices represents the value of the non-market service. For example, you may compare wages of workers exposed to an occupational risk to wages of workers not having that risk. The difference in wage is an estimate of the value of the occupational risk, assuming that all other factors are equal. The problem in hedonic pricing is to insure that all other factors are equal.

Contingent valuation methods
The method referred to as the contingent valuation method is based on survey techniques, where people are asked what their willingness is to pay (WTP) for a reduction in the pollutant or their willingness to accept (WTA) for an increase in the pollutant. The resulting values do not depend on the actual behaviour or market prices.

Contingent valuation is useful to estimation of the value of non-market goods and services. For instance WTP may be used to estimate the price of noise from a wind turbine.

2.8 Valuation of health risk

One of the most important parameters when estimating externalities is the valuation of human health risks. This parameter is the most significant and also the most controversial parameter in the assessment of external costs. The value of human health risks is estimated by the value of the risks to life. This may be valued either by society's willingness to avoid the risk or the willingness to be compensated to suffer this risk.

Health risk values are often expressed as the value of a human life. Aggregating the value to a single life makes comparison possible and therefore the expression "the value of a statistical life" (VSL) is used in many externality studies. VSL is calculated by estimating the willingness to pay (WTP) for a reduction in the risk of death. Though it has nothing to do with avoiding certain death. Estimates of WTP for a reduction in risk or the willingness to accept (WTA) of an increase in risk may be made by three different methods 1) wage risk, 2) contingent valuation, 3) consumer market surveys.

Using the wage risk method the increased compensation people need, other things being equal, to work in occupations where the risk of death at work is higher, is estimated. The contingent valuation method is based on surveys on peoples WTP and WTA for measures that reduce the risk of death from certain activities (e.g. driving) or their WTA for measures that increase it (e.g. increased road traffic in a given area). The third method is based on actual voluntary expenditures on items that reduce the risk of death from certain activities (e.g. stopping cigarette smoking or purchasing air bags for cars).

2.9 Discount rates

Discount rates are used to compare future economic costs with today's costs. Low discount rates weigh the future more heavily than high discount rates. The discount rate used in a study is therefore an important factor when comparing results from different studies.

There are several views on how discount rates should be used to value environmental resources. Some economists and utility experts argue for using rates similar to those used by utilities for valuing capital investments (e.g. 6 to 8 percent). This provides a consistent basis for utility resource selection decisions, but it also has the effect of reducing the value of damages that occur in the far future (e.g. global warming or nuclear waste storage) to nearly zero.

Low discount rates have the advantage of treating future generations equally to our own, but they also may cause relatively certain, near-term effects to be ignored in favour of more uncertain, long-term effects. Future generations may have new technologies and knowledge that will cheaply and easily deal with long-term environmental threats such as global warming.

In other studies a discount rate of zero has been used for moral reasons, particularly in the respect to human life and health risks.

The output of the global warming analysis is very sensitive to the discount rate, which is used to value future costs. This is because the impacts of global warming happen in the future, and are discounted by whatever rate is used, while the costs of mitigation occur in the present.

3. Differences in methodologies used for externality assessment

When comparing externalities for different fuel cycles it is important to use the same methodology for all fuel cycles, as it allows for a consistent comparison between the fuel cycles. Although uncertainty cannot be removed, at least some of it may be eliminated when the different fuel cycles are compared, as the estimation method is the same, and thus differences will be due only to each fuel cycle.

The following 7 studies have been chosen for further analysis and comparison.

- ExternE National Implementation
- IEA Greenhouse gas R&D Programme “Full Fuel Cycle”
- The New York Electricity Externality Study
- US-EC fuel cycle study
- Environmental costs of coal-based thermal power generation in India
- External costs in the Swiss Energy Sector
- Social costs of Energy Consumption

The studies have been chosen in order to cover as well old, well-known studies as new, unknown, but interesting studies. Some of the new studies are based on results from earlier studies, while others implement new ideas concerning the methodology. Most of the chosen studies are bottom-up studies using “The damage function approach”.

In the table below the results from the different studies have been translated to UScent/kWh year 1995.

Table 1 External costs in UScent/kWh year 1995 for different fuel cycles for the chosen studies

	Coal /Oil	Natural gas	Nuclear	Wind	Biomass
ExternE		NGCC: 0.9-10.15		Off-shore: 0.09-0.46 On land: 0.08-0.32	Biogas: 0.55-2.05
IEA	PC: -0.08-0.73	NGCC: 0.08-0.31 IGCC: 0.21-0.52			
New York	PC: 0.61 FB: 0.12	NGCC: 0.03			Wood: 0.47
US-EC	Coal: 0.06-0.14 Oil: 0.02-0.03	0.001-0.03	0.02-0.04		Wood: 0.21
India	Coal: 1.26				

Swiss	Oil:13.39-21.24	NGCC: 9.14-13.65	0.64-1.55		
Hohmeyer	Fossil fuels: 1.0-5.34	Fossil fuels: 1.0-5.34	1.05-10.53	On land:0.01	

PC: pulverised coal , FB: fluidised bed coal, NGCC: natural gas combined cycle, IGCC: Integrated gasification combined cycle

The results from the US-EC study are very low. One reason for this is that the global warming effect is not included in the results. The results from the Swiss study are rather high compared with results from the other studies. The results for natural gas in the ExternE study are high compared to the other studies. The reason for this is that external costs related to CO_2 are included in this study, while CO_2 is not included in the New York study, and in the IEA study CO_2 is captured.

The above comparison shows the importance of knowledge of which kind of methodologies have been used, which impacts are included etc. to explain why the numbers vary so much in different studies for the same fuel cycle. One thing evident is that the impacts, damages and externalities are very project specific. For example emissions expected from an integrated gasification combined cycle coal plant are considerably lower than from a pulverised fuel plant. The specifications of the plant to analyse will in this way affect the magnitude of the externalities. The specifications include as well installed pollution abatement technologies and their efficiencies as stack height and other source parameters that are used in atmospheric transport modelling. These parameters may be problematic to define for future technologies.

4. Overview of selected studies

The following overview gives a description of the selected studies in regard to which methodology has been used, the impacts included, valuation methods etc. The overview may give an estimate on why the external costs found in the different studies vary so much.

4.1 ExternE National Implementation

The objective of the ExternE National Implementation project (EC 1995), (Schleisner and Nielsen, 1997) has been to establish a comprehensive and comparable set of data on externalities of power generation for all EU member states and Norway. The tasks include the application of the ExternE methodology to the most important fuel cycles for each country.

The methodology used for assessment of externalities of the fuel cycles selected is a "bottom-up" methodology with a site-specific approach; i.e. it considers the effect of an additional fuel cycle, located in a specific place. The study estimates the damage costs related to different fuel cycles.

Quantification of impacts is achieved through the damage function approach. The study is using a unified approach to ensure compatibility between results. This is being achieved through the use of the EcoSense software package, which assesses the environmental impacts and resulting external costs from electricity generation systems. The system has an environment database at both a local and regional level including population, crops, building materials and forests. The system also incorporates two air transport models, allowing local and regional scale modelling. The model used for local modelling is a Gaussian plume model, while the model used for regional scaling is a receptor-orientated Lagrangian model. A set of impact assessment modules, based on linear dose-response relationships, and also a database of monetary values are included for different impacts. There is no model for ozone included in the software, but ozone is estimated as a simple relationship to NO_x.

As well local, regional as global impacts are assessed. The monetisation values used for CO_2 have been estimated using two different models. Four different values have been used: 3.8 ECU/t CO_2, 18 ECU/t, 46 ECU/t and 139 ECU/t CO_2. The estimate in Table 1 is based on a CO_2 value of 18 ECU/t.

The underlying principle for the economic valuation is to obtain the willingness to pay of the affected individuals to avoid a negative impact, or the willingness to accept the impact. A limited number of goods of interest to this study - crops, timber, building materials, etc. - are directly marketed, and for these valuation data are easy to obtain. However, many of the more important goods of concern are not directly marketed, including human health, ecological systems and non-timber benefits of forests. Alternative techniques have been developed for valuation of such goods, the main ones being hedonic pricing, travel cost methods and contingent valuation.

The central discount rate used for the study is 3%, with upper and lower rates of 0% and 10% also used to show sensitivity to the discount rate. For the valuation of health risk a value of 3.1 MECU has been used for the value of a statistical life. This value has been used for valuing fatal accidents, mortality impacts in climate change modelling and similar cases where the impact is sudden and where the affected population is similar to the general population for which the VSL applies. In the case of deaths arising from illness caused by air pollution the YOLL (years of life lost) approach has been used. YOLL depends on a number of factors such as how long it takes for the exposure to result in illness and the survival time for the individuals.

The base year for the valuation is 1995, and all values are referring to that year. The study is from 1997. A wide range of technologies has been analysed, covering more than 60 cases for 15 countries and 11 fuel cycles including fossil fuels, nuclear and renewables.

4.2 IEA Greenhouse gas R&D Programme "Full Fuel Cycle"

This study (ETSU, 1994) is based on a "bottom-up" approach assessing the damage costs related to the full fuel cycles of three types of power plants: Natural Gas Combined Cycle (NGCC), Integrated Gasification Combined Cycle (IGCC) and Pulverised Fuel (PF). The study is from 1994.

The power generation plants are combined with three options for abatement of CO_2 emissions: Disposal of CO_2 to disused gas wells, disposal of CO_2 to the deep ocean and sequestration of CO_2 to a sustainable forest. 2005 has been selected as the base year, being the earliest date for CO_2 abatement technologies to be available. The technologies assessed are as advanced as possible.

The study is based on the first ExternE study (CEC, 1995a-f), and the methodology used in the project is the damage function approach. The study is based on a LCA including all stages of the fuel cycle from extraction of fuel to waste disposal and electricity transmission as far as the national grid. The ExternE methodology has been improved in the study especially concerning the greenhouse gas effect.

The dose-response functions used in the study are derived from the results of several other studies, especially the ExternE study. The used functions are linear relationships. Concerning global warming the study follows the IPCC impact methodology. A computer model has been used to estimate climate changes caused by greenhouse gases. The period for implications of greenhouse gases has been restricted to 100 years.

Two models have been used to describe the transport and chemistry of atmospheric pollutants. Gaussian plume models have not been used, because these models are for short ranges about 50 km, while the actual cases have larger ranges.

Economic valuation is in some cases based on market prices, in other cases prices are based on published studies using contingent valuation, hedonic pricing, travel costs methods or other related techniques. The study uses a discount rate of 1.5 % for environmental externalities.

The valuation of health risk is based on statistical risk and not on the willingness for the individual to pay to avoid a certain death. A value of 3 million $ has been used for VSL, which is within the range conventionally used in USA or UK based studies.

CO_2 has not been valued, as it is assumed that the CO_2 is disposed into the ocean or sequestered. However, these options have not been monetised.

4.3 The New York Electricity Externality Study

In this study (Rowe et al, 1995) the EXMOD model is used, developed at the Tellus Institute in Boston. The model is similar to the European EcoSense model. The EXMOD model is an American model, that models air dispersion from locations in New York to receptor cells throughout the north-eastern U.S. and eastern Canada. The study is from 1995.

The study is a bottom-up study based upon "The damage function approach". In the study damage costs are estimated for 23 new electric resource options within coal, oil, natural gas, nuclear, municipal solid waste, hydroelectric, biomass, wind, solar and demand side management. Default air emission rates, land use and other characteristics are specified for each facility in the model, but these characteristics may be replaced. The air dispersion models in EXMOD are annual average or simple peak models used by U.S. regulatory agencies. The two models are used to predict short-range changes (<50 km) and long-range changes (50-1500 km) covering local and regional range. Also ozone models are included driven by changes in NO_x concentrations. So far the model does not compute CO_2 damages (i.e. EXMOD implicitly assumes 0$/ton CO_2). However, it is possible to include other values for CO_2.

Impact calculations are based on dose-response parameters in EXMOD with default high, central and low parameter values. Based on a review of the literature EXMOD uses a central VSL estimate of 4.0 million $ for individuals under 65 years, and a central estimate of 3.0 million $ for individuals of 65 years or older. The argument for that VSL decreases with age is that years of expected remaining life decrease with age. Thus life expectancy and health status tend to decrease with age so that the quality of life is reduced.

The study uses control cost valuation to estimate the environmental cost associated with various air emissions. For other impacts the study uses the contingent valuation method.

4.4 US-EC fuel cycle study

This study (Oak Ridge, 1992) is the American part of the ExternE study using "The damage function approach". The study is based on a bottom-up approach estimating the marginal consequences of a fuel. The fuel cycles included in the study are coal, biomass, oil, natural gas, hydro and nuclear.

Atmospheric transport models are used to estimate concentrations of pollutants in the air. Gaussian plume models are used for primary pollutants such as particulates, NO_2, SO_2 and air toxics. The study focuses on local and regional damages. Dose-response functions are based on empirical relationships derived through statistical analysis of measured data.

The economic valuation is primarily based on individuals' WTP. The value of things like recreational resources is based on other studies, which account for travel expenses and time to travel to the site. In other situations contingent valuation is used to estimate WTP to avoid undesirable outcomes in hypothetical situations. Ozone and global warming damages have not been monetised in the study.

A major disadvantage of the used methodology has been that data- and computationally it is very intensive. This limitation has been modified in the ExternE National Implementation study with the development of the EcoSense model. The study was finished in 1992. A discount rate of 3 % has been used for the base case in the study.

4.5 Environmental costs of coal-based thermal power generation in India

In this study (Bhattacharyva, 1997) an attempt has been made to estimate the environmental costs of coal-based thermal power generation in India. The study is based on a bottom-up approach. The analysis is principally concerned with the power generation phase from a coal-fired plant, though the environmental costs of coal production have been covered to a lesser extent. The methodology used to evaluate the impacts of pollution from power generation is the damage function approach, while estimates of the environmental costs of coal production are based on control costs. The external costs mentioned in Table 1 only covers the costs related to power production.

A Gaussian model has been used for the analysis of dispersion of pollutants. The damage functions used in the study are based on existing survey data from an industrial area of Bombay. The damage functions used are linear or logarithmic functions. Damages have only been monetised for SO_2 and particulates. Only mortality, morbidity and effects on buildings have been taken into account. Damages due to NO_x have not been estimated monetarily owing to possible double counting problems. CO_2 emissions are not taken into account. The study is from 1994.

Morbidity has been valued by using the price of hospital visits and medicine costs, while effects on buildings have been monetised by using a loss in rent for the buildings. Mortality is valued by using a very low VSL of 287,230 rupees (9044 US$).

4.6 External costs in the Swiss Energy Sector

This study (Ott, 1995) is based upon information from earlier externality studies. The external costs are estimated for the Swiss energy sector as a whole. The analysis is using a top-down approach, estimating the externalities e.g. per ton emission followed by a conversion to price per kWh for different fuels.

The methodology used is “The damage function approach”. The external effects are identified based on a LCA of energy processes. For the quantification process available information on physical effects of the identified externalities have been collected and evaluated. Only regional and global damages are identified and monetised. Air pollution, oil spills, health injuries etc. is valued by a damage cost approach. Atmospheric models have not been used, as the impacts are based on results from other studies. Also dose-response functions are based on other studies. For the cost of greenhouse gas emissions an avoidance cost approach has been used by assessing the costs of achieving a CO_2 reduction target by 2025. The avoidance costs based on WTP have been monetised to 160-230 US$/t CO_2. Impairments of natural landscapes by energy infrastructures as well as loss of human life as a result of energy related activities are valued by using willingness to pay data. Other costs have been valued by using market prices. The analysis is from 1994. The prices are based on data from 1990.

Damages to human health have been based on a German study, which has been transferred to Switzerland. Economic valuation is based on the human capital approach, which underestimates real costs (it only includes expenditures in the health sector, salary payments and sickness benefits for employees being unable to work).

4.7 Social costs of Energy Consumption

This study (Hohmeyer, 1988) was the first attempt to assess the external costs related to energy production. Hohmeyers study is a “top-down” study. All fossil fuels are calculated as one case, not including any kind of LCA. As a value for annual emissions the limit values for fossil fuels in Germany are used. Multiplying these emissions with a toxicity factor results in weighed emissions, resulting in a damage factor of 28 % for electricity generation from fossil fuels.

The damages to flora, fauna, mankind, materials and climate change have been calculated using German economic values for forest, materials etc. No dispersion models have been used. The damages are summed up to a total in million DM/a, and then divided by the annual electricity generation. The study is from 1988, but the costs are in 1982 prices.

Its cost estimates are based on several sources. Some estimates come directly from other studies that value specific categories of effects (e.g., human health effects of air pollution). Other estimates involve direct calculations based on damages (e.g., estimating the probability of and health effects from a nuclear accident and multiplying by the monetary value of a life). Finally, a few estimates involve the costs of mitigating environmental damages (e.g., the costs of avoiding the effects of sea level rise brought on by global warming).

Effects on climate are calculated based on the assumption that a doubling of the CO_2 concentration in the atmosphere will lead to a general rise of temperature levels of 1.5-5.5 degrees C, resulting in a rise of the main sea level by app. 25-165 cm, and lead to severe damage in coastal areas. For Germany this will result in a necessary increase in height of the coastal defence works of a total length of app. 1000 km. The costs are recalculated to costs per year over a period of 50 years and only related to CO_2 emissions from fossil fuels. The value transferred to CO_2 emissions give a very small estimate of 7-14 \$/t CO_2 in 1982. These costs being mitigation costs are not directly comparable to the CO_2 costs calculated in other studies as damage costs.

Valuation of health risk has been estimated based on other studies, which assume that air pollution will lead to decreased availability of the production factor labour or to casualties of the production factor labour. Therefore health risk has been valued as loss in production per year and the term VSL has not been used.

5. Comparison of results

Table 2 gives an overview of the methods used, the costs related to global warming and the value of a statistical life used in the different studies. The results shown for natural gas and coal are for all studies in US$ year 1995. The other costs are related to the reference year for the study.

It should be noted that the Swiss study and Hohmeyers study are “top-down” studies, while the rest of the studies are “bottom-up” studies using the damage function approach. Only the Swiss study, Hohmeyer and the ExternE study monetise global warming. Hohmeyer uses mitigation costs for monetisation resulting in a very low cost for global warming. The estimate for natural gas from Hohmeyer is therefore comparable to the other studies without global warming. The Swiss study has the highest estimate for natural gas (9.1-13.6 UScent/kWh), but uses also high costs for global warming. The highest value for global warming in the ExternE study (139 ECU/t CO_2 (180 $)) equals the value used in the Swiss study. If this value is used for global warming in the ExternE study the estimate for natural gas is10.15 UScent/kWh, which corresponds to the Swiss estimate.

A conspicuous parameter is the value of VSL used in the Indian study (9320$) compared to the values used in the other studies (around 3-4 mio $). However, the results for coal in India are still high compared to the other studies.

Table 2 Comparison of the different studies

	ExternE	IEA	New York	US-EC	India	Swiss	Hohmeyer
Approach	Bottom-up	Bottom-up	Bottom-up	Bottom-up	Bottom-up	Top-down	Top-down
Costs	Damage costs	Damage costs	Damage costs	Damage costs	Damage costs	Damage costs	Damage costs
Methodology	Damage function	Damage function	Damage function	Damage function	Damage function	Damage function	Other studies approaches
Atm. Modelling	Gaussian plume model, Receptor-orientated Lagrangian model No ozone modelling	Two models for transport and chemistry of pollutants	Annual average model, Simple peak model, Ozone model	Gaussian plume models	Gaussian model	No dispersion models	No dispersion models
Dose-response	Linear	Linear	Default high, central and low parameters	Linear	Linear, logarithmic	Based on other studies	Based on other studies
Damages	Local, regional, global	Local, regional, global	Local, regional, (global)	Local, regional	Regional (SO_2, particulates)	Regional, Global	Local, regional ,global
Global warming	3.8-139 ECU/t CO_2 (18 ECU as central)	CO_2 storage	0 $/t CO_2	-	-	160-230 $/ t CO_2	0.03-0.05DM/t CO_2 (mitigation costs)
Valuation Methods	WTP, market price, Hedonic pricing, CV	WTP, market price, Hedonic pricing, CV	CCV, CV	WTP, CV, Travel costs	Market price, Loss in rent	WTP Market price	WTP Market price
VSL	3.1 MECU	3 million $	4 mio $(< age 65) 3 mio $(>= age 65))	?	287230 rupees (9320 $)	?	-
Discount rate	3%	1.5%	?	3%	?	?	?
Reference year	1995	1994	1995	1992	1994	1990	1982
Estimate for natural gas (1995)	0.9-10.15 UScent/kWh (1.9 UScent/kWh as central)	0.08-0.31 UScent/kWh	0.03 Uscent/kWh	0.01-0.03 UScent/kWh		9.1-13.6 UScent/kWh	1.0-5.7 UScent/kWh

Estimate for coal (1995)	-	-0.08-0.73 UScent/kWh	0.61 UScent/kWh	0.06-0.14 UScent/kWh	1.26 UScent/kWh		1.0-5.7 UScent/kWh

6. Utilisation of externality estimations in different countries

Different policy mechanisms may be used in order to internalise externalities. Most of those mechanisms are discussed in the Review Paper of International Renewable Energy Policies. Three approaches, however, will be discussed in this paper, as these approaches are used in the United States for incorporation of externalities. The approaches mentioned by Pearce and others (1992) are ranking with grandfathering, taxation with grandfathering and complete emission taxation (IEA 1996). Other methodologies are discussed in the Review Paper of International Renewable Energy Policies.

Ranking with grandfathering only affects investments in new capacity (therefore the term grandfathering). It is the weakest option, but also the least sensitive to errors. Externalities are only used as a measurement for ranking new capacity, and there is no requirement to incorporate taxes in electricity tariffs either for new plants are existing capacity. This approach has been used in the United States as part of integrated resource planning (IRP). In seven states (California, Massachusetts, Minnesota, Nevada, New York, Oregon and Wisconsin) rules, statutes or other legal considerations exist requiring that the utilities consider externalities, and on account of this these states have incorporated monetary values when assessing externalities in order to choose energy supply and demand options. Massachusetts no longer uses monetised externality values due to a decision made by the State Supreme Court in 1994. However, external costs are still considered in utility demand side management programmes and the resource decision process. 16 other states (Colorado, Connecticut, Delaware, Georgia, Hawaii, Illinois, Iowa, Missouri, New Hampshire, New Jersey, North Carolina, Ohio, Texas, Utah, Vermont and Washington) have incorporated external costs in some way in regulations controlling IRP or other aspects of utility planning.

Taxation with grandfathering influences new plants and investment decisions. Electricity production from new plants is subject to a tax derived from consideration of externalities. There may be problems in using this approach in the development of new plants, because the utilities may prefer existing polluting plants without taxes instead of new plants with lower emissions but which are taxed. Taxation with grandfathering may therefore in some cases result in a postponement of a decrease in emissions.

Under complete emission taxation as well existing plants as new plants are affected, as electricity production from all plants is taxed based on the calculated value for externalities. This approach seems fairer regarding the development of new capacity. However, there is the possibility that utilities will totally close existing polluting plants. Also there exists the possibility that industry may switch fuel, and instead of using taxed electricity will use other sources, that are less stringently regulated. This may also increase the emissions.

Five states in US (Arizona, Kansas, Maine, Montana and New Mexico) are assessing the possibility of requiring the utilities to consider externalities in their IRP, while 12 other states have no current requirement, but have signalled that they may require the utilities to consider externalities in the future.

In Europe usually environmental impacts are not valued in monetary terms (Staale, 1997), but different externality studies have been carried out (chapter 1). Germany has been an exception since noise, air pollution and other impacts from road traffic have been valued. As far as known there is no legal requirement for cost benefit analysis or incorporating external costs of projects in any European country.

In Europe the ExternE project has been a major step forward in the assessment of environmental and social damages associated with energy use. It has established a methodology and accounting framework for the comparable assessment of the externalities from a wide range of different fuel cycles. The study should provide valuable input both for the debate on the internalisation of external costs in energy pricing and the consideration of externalities in energy policy decisions.

7. Variation of external costs using the same methodology in different countries

The analysis of externalities and valuation of external costs can provide decision-makers with an additional tool. However, using external costs is subject to many difficulties and uncertainties. In chapter 2 difficulties and uncertainties in using different methodologies were outlined, and differences in external costs may also appear using the same methodology in different ways. The following will focus on why the numbers are different using the same methodology.

The methodology analysed is the ExternE methodology used for the wind fuel cycle in different countries. The countries involved in the comparison are Denmark, Spain, United Kingdom and Greece. In Denmark the analysis has been made for as well an off-shore wind farm as a wind farm on land. In the United Kingdom the analysis has been made for a large wind farm of 30 MW (103 turbines) in the countryside and a smaller wind farm at 4 MW (10 turbines) close to an inhabited area. The capacity and size of the wind farms in Denmark, Spain and Greece is close to the smaller wind farm in UK.

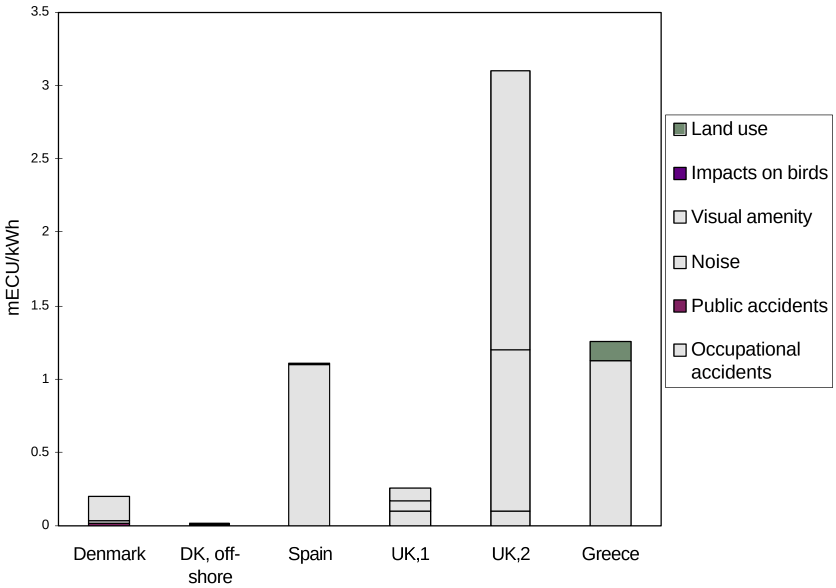

Figure 1 External costs related to local and regional damages from the wind fuel cycle

Figure 1 shows the external costs related to local and regional damages from the wind fuel cycle implemented in different countries. As seen from the figure the external costs vary considerably although the same methodology has been used in all countries. Also the importance of the different damages varies from country to country. In the case of UK,2 and Denmark visual amenity causes the largest external costs, while noise is the most important damage in Greece and also quite important in UK. In Spain occupational accidents are dominating.

Damages like noise and visual amenity are very site dependent. Figure 2 shows the damages due to noise for the Danish, Spanish, English and Greek implementation of ExternE based on calculations from the same logarithmic formula, which includes the distance from the wind turbine. The formula is adjusted for the variation between night and day sensitivity, irregular operation, noise sensitivity of people and background noise.

The large difference in UK,1 and UK,2 is that UK,1 is situated in the countryside while UK,2 is situated close to a town. The Danish wind farm on land is situated nearby smaller villages. Had the wind farm been situated close to a town the damages would have been much larger.

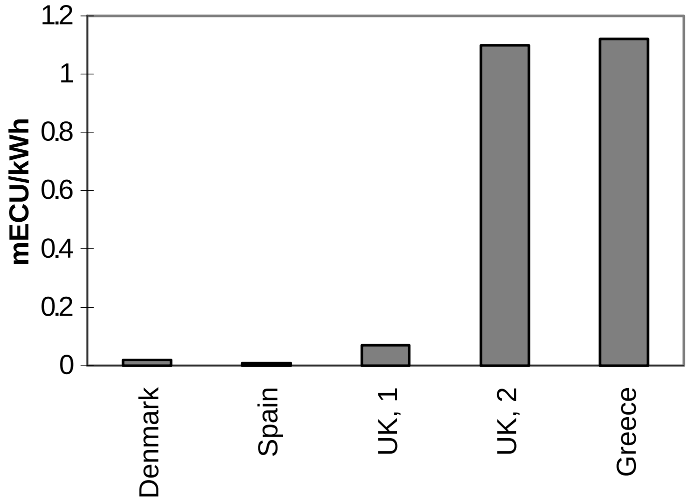

Figure 2 Damages due to noise for the Danish, Spanish, English and Greek implementation of ExternE

The formula includes a noise depreciation sensitivity index, NDSI. The large difference in the noise damages between the countries is, apart from the location, also caused by the use of different NDSI values and different discount rates. Using the same values would result in damages as shown in Figure 3. The noise from the Greek and UK wind farms is reduced by a factor 5.

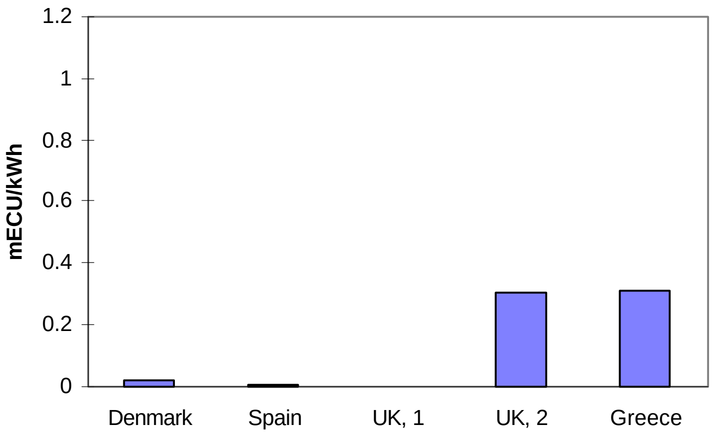

Figure 3 Damages due to noise using same values of NDSI

Regarding the external costs related to occupational accidents, the costs are much larger for Spain than for the other countries. Comparing the accidents for Spain with the accidents for Denmark shows an amount of about 100 times more accidents registered per TWh in Spain than in Denmark, although the amount of accidents are not site specific. The primary reason for the difference is that the accidents registered in Denmark are concrete accidents related to construction and operation of a wind farm, while the accidents registered in the case of Spain are based on information of accidents related to statistical groups like construction, engineering etc.

The comparison of the wind fuel cycle for different countries shows that even though the same methodology has been used to assess the external costs related to a specific fuel cycle, the results are not unambiguously comparable. The analysis of data used is still important.

8. Non-environmental externalities

In the previous chapters only environmental externalities have been mentioned. However, there are also numerous non-environmental externalities related to energy production (e.g. effects on employment, infrastructure, reliability in capacity supply etc.). These externalities have generally obtained much less attention than externalities associated with environmental impacts. In the following a few examples of non-environmental externalities are given.

Energy security may be a non-environmental externality related to energy production from different kinds of fuels. The energy security may be threatened, if the energy supply from some fuels suddenly is disrupted either because of parameters like war, terrorism, or natural catastrophes, or because of price rises.

Another kind of non-environmental externality is reliability or capacity credits. Supplies from some energy technologies may be unreliable or fluctuating, as for instance hydropower or wind power, and some kind of back-up system is needed.

The location of a power station may affect the local infrastructure in a positive as well as a negative way. For example the local transport and telecommunication system may be improved because of the presence of the power plant. On the other hand the roads may be damaged because of improved traffic. This may be regarded as a non-environmental externality.

Non-environmental externalities are also associated with research and development. In the past many governments have funded research in different energy sources, which may be considered as an externality for this energy source. However, care has to be taken as to whether the externality has already been internalised.

Effects on employment may also be considered as a non-environmental externality related to the construction and location of the energy production plant. Construction and operation of a new power plant will increase the need for work in the area.

9. Conclusion

This report has pointed out different parameters, which are important to consider when externalities estimated for the same fuel cycle in different studies are compared. Some studies transfer dose-response functions and monetisation values from other studies. It must be considered carefully for each of the functions if it is possible to use functions from other studies, or if it is necessary to develop a function for a new region. In the case of Thailand it must be considered if dose-response functions for health effects of air pollutants can be derived from studies in the USA or Europe. There is good reason to suspect that there will be some variation resulting from the affected population, the exact composition of the pollutants that the study group was exposed to, etc.

Also it is important to consider the purpose of the externality study. At a policy level "top-down" analyses are useful, because policies mostly address average costs. On the other hand, for environmental costing purposes "bottom-up" analyses are useful, as it is the environmental cost of a new proposed resource that must be selected based on marginal costs.

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